USING FUEL TREATMENT AND SITE CHARACTERISTICS TO MODEL STAND REPLACEMENT FIRE IN REGENERATION STANDS FOLLOWING THE 1994 WILDFIRES ON THE KOOTENAI NATIONAL FOREST

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ABSTRACT

In 1994 fire managers on the Kootenai National Forest observed that wildfires produced regeneration loss in some stands and not in others. The question was what site characteristics and management activities were responsible for this loss. To address this question a logistic regression model was applied to a set of regeneration stands (n=135) located on the Libby, Rexford, and Three Rivers ranger districts. The occurrence of a stand replacement fire was modeled as a logistic function of aspect, habitat type, fuel treatment, and logarithm of trees per acre with R^2=0.523. Odds ratios derived from logistic regression indicated which categories within a variable were most at risk for a stand replacement fire and subsequent regeneration loss. Southwest and south aspects had the highest odds ratio (22 and 9) for the aspect variable. Two habitat types had the most noted comparison. Western hemlock/queencup beadlily (*Tsuga heterophylla/Clintonia uniflora)* had an odds ratio of 30 and the Western red cedar/queencup beadlily (*Thuja plicata/Clintonia uniflora)* had an odds ratio of 17. For the fuel treatment variable, the no fuel treatment category had the highest odds ratio of 11. Stand replacement fire stands had a mean log(TPA) significantly different ($p<0.001$) from that of non-stand replacement fire stands. A significant difference ($p<0.05$) in mean log(TPA) by aspect and fuel treatment but not habitat type category was detected by ANOVA procedures. A downward trend in mean log(TPA) was observed from northerly to southerly aspects. Piled and burned stands had a greater and significantly different ($p<0.05$) mean log(TPA) than stands that had been broadcast, understory, or jackpot burned. Regeneration stands with a southerly aspect, belonging to the cedar-hemlock habitat type, having no fuel treatment, and low mean log(TPA) are most at risk to have stand replacement fire and subsequent regeneration loss. Competition from understroy vegetation may explain these findings. Bracken fern (*Pteridium aquilinum*), commonly found in cedar-hemlock stands and on southerly aspects, may out-compete tree seedlings and provide a fine fuel hazard.

Keywords: fuel treatment, stand replacement fire, risk, regeneration

INTRODUCTION

Long term drought conditions leading into the 1994 fire season set the stage for what has been described as a 20 to 50 year fire event (personal communications, KNF staff 1997). Weather data taken from July 1st through September 30th 1994 at the Libby Ranger Station indicate that the Energy Release Component (ERC) indexes were above the 89th percentile for 66 out of 92 days (72%) for the National Fire Danger Rating System fuel model G (heavy timber). In comparison, only 30 out of 92 days (33%) for 1988 and 29 out of 92 days

(32%) for 1998 had ERC indexes above the 89th percentile (Bradshaw 1999).

During mid-August of 1994, the Kootenai National Forest (KNF) experienced the start of over 160 lightning-caused fires that burned approximately 53,000 acres (Kootenai National Forest, 1994). Resources became limited and suppression forces were not able to prevent regeneration loss in intensively managed stands.

Reconnaissance surveys conducted by USFS personnel during the summer of 1995 documented regeneration mortality in intensively managed forest stands. Some stands experienced a stand replacement fire with regeneration mortality. Other stands, however, seemed fire resistant experiencing only an underburn.

Those stands that experienced the effect of a stand replacement fire were coded as 4250 in the Activities file of the Oracle database. This coding was assigned to stands that experienced partial or complete regeneration mortality. Stands that experienced sufficient regeneration mortality to reduce stocking to less than 300 trees per acre were replanted. Those stands that experienced fire that reduced the existing fuels, but did not create a change in the character of the stand were coded as 4981. These stands did not have any regeneration mortality or need replanting.

The fire behavior models constructed by Albini (1976) identify the independent variables that predict the rates of spread, growth, flame front, and duff burned off by a fire. Some of these independent variables are wind speed, slope, aspect, fuel characteristics, and temperature. Fire behavior, and the subsequent effects of a particular fire on vegetation, are dependent on site characteristics such as slope and aspect as well as weather conditions during the fire (Rothermel 1983).

A few researchers have investigated the relationship between fuel loads of managed and unmanaged stands. Omi and Kalabokidis (1991) examined the relationship between fuel loads, fire severity, and fire damage in extensively managed (not harvested) mature forests and intensively managed (clear-cut) stands that burned during the 1988 Greater Yellowstone fires. They found that mature extensively managed stands supported higher fuel loads and experienced greater burn severity compared to intensively managed clearcuts.

Vihnanek and Ottmar (1994) investigated the effects of the 1988 Shady Beach wildfire that occurred on the Willamette National Forest, on untreated and treated logging slash areas. Results showed that less fuel was consumed on units that had been treated compared to those that were untreated.

A study conducted by Weatherspoon and Skinner (1995) on the Klamath National Forest in ponderosa pine and Douglas-fir habitat types found several independent variables to be significant predictors with fire damage in plantations. Six variables; Grasses, Forbs, Elevation, Site Prep None, Site Prep Machine Piled, and Damage in Adjacent Stand, were the most significant (Weatherspoon and Skinner 1995). The amount of Grasses, Site Prep None, and Damage in Adjacent Stand were positively correlated with fire damage class while the other variables were negatively correlated. The strongest relationship was between the damage in the adjacent stand and damage in the regeneration stand. Comparison of fuel treatments indicated that broadcast burning resulted in the least stand damage and no site preparation resulted in the greatest damage. Mechanical piling and burning resulted in neither an increase nor decrease in regeneration damage. Furthermore, those stands that were broadcast burned suffered significantly less damage, while stands receiving machine pile and burn treatments had suffered intermediate damage. Those harvested stands that had no site preparation burned completely and severely, resulting in total loss (Skinner and Weatherspoon 1996).

The US Forest Service is mandated to have regeneration stands “stocked” within five years after harvest. Large sums of time, money, and effort are expended in the nursery growth of seedlings, as well as in the planting of these harvested stands. Thus, this study explores the plausibility of predicting regeneration mortality due to wildfire under varying fuel treatment and site characteristic conditions to allow resource managers to apply the appropriate treatments to help prevent this loss.

OBJECTIVES

The three objectives of this study were:

1. Construct a model predicting the occurrence of a stand replacement wildfire (dependent variable) as a function of site characteristics and management activities (independent variables).

2. Validate the prediction model constructed under objective one.

3. Compare the means of selected independent continuous variables across classes of other selected independent categorical variables.

STUDY AREA

Three ranger districts, Libby, Rexford, and Three Rivers, of the Kootenai National Forest (KNF) were included in this study. The KNF occupies 2.2 million acres in the northwest corner of Montana and a small portion of the Idaho panhandle (Figure 1) (Impact Assessment Inc. 1995).

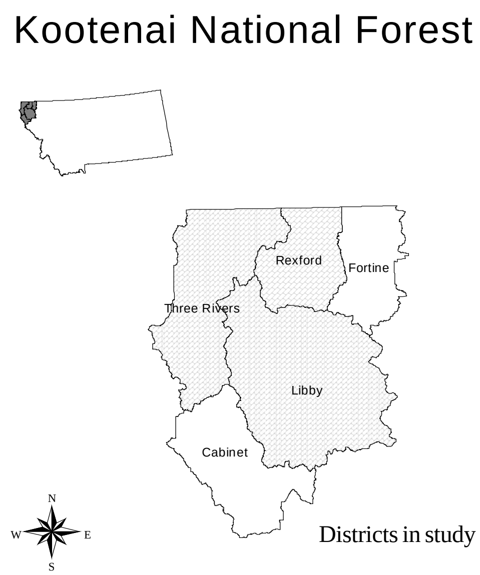

Figure 1. Map of the ranger districts on the Kootenai National Forest.

The first timber sale occurred in 1904, four years before the KNF was established from forest reserves in 1908 (Northwest Archaeological Associates, Inc. 1994). The federal government owns approximately 77 percent of the land within the KNF of which 56 percent are suitable for timber management (Impact Assessment Inc. 1995). The average annual timber harvest for the period 1960 to 1990 was 192 million board feet per year with a range of 131.5 to 248.3 million board feet per year (Impact Assessment, Inc. 1995).

The geological history of the KNF includes metamorphosed sedimentary rock of the Belt Supergroup deposited from an inland sea that occurred 800MM to 1,400 MM years ago. Sands, silts, clays, and carbonate materials were compressed into quartzites, siltites, clays, and limestone (USDA Forest Service, 1996).

Mountainous areas of the forest have alpine features, while the valley bottoms have continental glacial features. Soils in the valley are "a mixture of sorted sands and silts, layered gravels, and unsorted sands, silts and gravels." The upland soils are "a mixture of silts and rock" resulting from glacial till. At higher elevations, there are more sands than silt and higher rock composition. Volcanic ash blankets the soils of higher elevations (USDA Forest Service, 1996).

Elevation ranges from 1,820 ft in the Yaak River valley to 8,712 ft at Snowshoe Peak (Impact Assessment, Inc. 1995). The Maritime Climatic regime persists during the winter while the Continental climatic regime persists during the summer. Winters are cool and wet while summers are warm and dry (USDA Forest Service, 1996). Precipitation in the lower elevations ranges from less than 14 to 20 inches while at higher elevations it ranges from 80 to over 100 inches (USDA Forest Service, 1996). Precipitation comes in the form of rain in the valleys and snow in the mountains.

METHODS

Data Collection / Organization

Three ranger districts, Three Rivers, combined Libby, and Rexford, of the KNF were the focus of this study. These three ranger districts experienced the most fires and contained the majority of the regeneration stands within the 1994 fire boundaries (n=135). Site characteristic and management activity data from the Oracle database were used to assess the occurrence of a stand replacement fire regeneration stands.

Each ranger district was visited to gather data from the Timber Stand Management Record System (TSMRS) and from personnel regarding the regeneration stands that were effected by the 1994 fires. The TSMRS has three components: index maps, stand folders, and the Oracle database. The stand folders contain all the attribute data of stands. This includes stand examination data, silvicultural prescriptions, activity maps, and narrative reports. The Oracle database contains all the automated current and past stand data (USDA Forest Service, 1996).

During visits to each ranger district, the identification of regeneration stands that were within the fire boundaries was accomplished through the Forest Assessment of the 1994 fires, TSMRS, and personal communications. Narrative descriptions of fire events were recorded from suppression personnel. Information on suppression tactics (if any) applied to the regeneration stands was also gathered from discussions with fire staff. Stand folders were examined for pre- and post-harvest surveys, silvicultural prescriptions, and any burn plans containing information on fuel loads. Weather station records, Energy Release Component (ERC) and Burning Index (BI) data were collected.

Discussions with KNF staff and researchers determined that there were 19 possible independent variables to be considered in this study (Table 1).

#	INDEPENDENT VARIABLE	INCLUDED IN ANALYSIS
1	Aspect	Yes
2	Elevation	Yes
3	Equipment Type	Yes
4	Fire Group	Yes*
5	Forest Type	Yes
6	Habitat Type	Yes
7	Slope	Yes
8	Stand Position on Slope	Yes*
9	Trees/Acre	Yes
10	Type of Treatment	Yes
11	Vegetative Response Unit	Yes*
12	Year of Origin	Yes
13	Burning Index	No
14	Energy Release Component	No
15	Fuel Load	No
16	Stand Size Class	No
17	Thinning Prior to 1994	No
18	Type of Fuel	No
19	Weather **	No

Table 1. Independent variables in study.
***** Derived variables
** Weather is a factor. Includes the variable temperature, relative humidity, and wind speed.

Stand Selection

The Regional Office conducted a query of the entire KNF Oracle database and provided a list of regeneration stands that had experienced fire. This query was based on the harvest and fire codes (4250 and 4981). A list of all regeneration stand numbers for this study was developed. This list was then used to develop the database of all the study variables.

Stands were included in this study based on the following criteria:

1. Stands no greater than 20 years old.

2. Stands within Three Rivers (D4, Troy) Rexford (D1, Eureka) and combined Libby (D6) districts.

3. Stands without intermediate harvest methods.

4. Stands without thinning.

Murphy Lake (D3, Fortine) and Cabinet (D7, Trout Creek) were excluded due to the low number of stands (n=10).

According to district personnel, a regeneration stand is no longer defined as a regeneration stand 15-20 years after stand initiation. Thus, stands that had undergone stand initiation after to 1974 and less than 20 years old were included in this study.

As recommended by collaborative researchers, stands that had undergone intermediate harvest methods were also excluded. None of the stands in this study were influenced by fire suppression activities during the 1994 fire season.

Independent Variables Excluded from Analysis

Of the 19 possible independent variables identified by district personnel, eight were not found in the Oracle database or stand files and seven were not included in analysis (Table 1). These were BI, ERC, Fuel Load, Stand Size Class, Thinning Prior to 1994, Type of Fuel, and Weather.

Although they are important components that affect fire behavior, ERC, BI, and Weather were excluded from this study because measurements were not recorded for each stand. Furthermore, only three stands in the study had thinning done prior to 1994 which was too small a sample size to include precommercial thinning in the study. Finally, Fuel load data and type of fuel were completely absent in the Oracle database or incomplete in the stand files and thus were not included.

Stand size class information was updated after the 1994 fires. Many of the stands size classes changed to non-stocked. Unlike the activity files, the basic stand data file does not contain the historic data. Rather only, the most recent information is kept in the file. Thus, stand size class was not included in the analysis.

Independent Variables Included in Analysis

Of the 12 variables included in the analysis, three were not present in the Oracle database or stand files (Table 1). Thus, the variables Fire Group, Stand Position on Slope, and Vegetative Response Unit were derived by other means.

The variable Fire Group was determined by placing the stands that were classified based on the Pfister et al 1977 habitat types into the fire groups derived by Fischer and Bradley (1987).

A Digital Elevation Model was used to determine the position of each stand on the slope. Slope position was determined by placing Arc/Info boundary coverage on top of a shaded-relief map in ArcView and visually determining the stand position on the slope in five classes. The five classes were valley bottom; lower, middle, and upper slope; and ridge top. The streamlines theme was used to assist in visually determining the slope position.

The vegetative response unit (VRU) for each stand was derived by similar methods, as was slope position. The Supervisor's Office used Arc/Info and placed the stand boundary coverage on top of the VRU coverage. Using ArcView, they provided printed maps of the stand boundaries and VRUs. The VRU for a stand was determined visually and in the case where a stand consisted of more than one VRU, the VRU that consisted of the majority of the stand was chosen.

The stand year of origin, as defined by KNF staff, is the same as reforestation year in the Oracle database. Reforestation year is defined as the year when stand initiation actions were taken. Type of treatment included harvest, fuel, and site preparation.

Independent Variable Categorization

The selection of the 12 independent variables thought to best depict the stand replacement fire in regeneration stands was based on suggestions from KNF personnel, literature review, and univariate regression analysis (Table 1).

Category definitions associated with each independent variable were based on what made the greatest ecological sense, with the exception of habitat type in which groupings were based on the number of observations per category. Attempts were made to categorize candidate independent variables in several ways in order to explore any possible significance of the variable to model construction. With the exception of habitat type, reference categories associated with each independent variable were identified as those having the least proportional occurrence of a stand replacement fire. The Subalpine Fir/Sitka Alder habitat type was chosen over the Subalpine Fir/habitat type because of its larger sample size and comparable low occurrence of a stand replacement fire.

In the database constructed for this study, fuel treatment was split into three classes: fuel treatment 1, 2, and 3. These fuel treatment classes were based on type and the sequence in which fuel treatments occurred. Fuel treatment 1 is defined as all those treatments that dealt with moving the fuel (lopping, mechanical piling, and dozer piling) subsequent to fuel treatment 1. If a fuel treatment 1 occurred, then it was the first treatment to occur in the sequence. Fuel treatment 2 and 3 refer to the type of burning that was applied to the fuels (burn dozer piles, burn mechanical piles, broadcast, jackpot, and understory burn).

If a stand had been dozer or mechanical piled and burned, it was categorized as pile and burn. If a stand had been understory, broadcast, or jackpot burned, it was categorized as burned. Likewise, if no sequence of fuel treatments had been applied to the stand, it was categorized as no treatment. The no treatment category also included stands that had been piled but not burned.

Data Analysis

Objective one, construction of a prediction model, was accomplished by using logistic regression techniques outlined by Hosmer and Lemeshow (1989) and using SPSS Professional Statistics 7.5 software (Norusis, 1997). The dependent variable is the occurrence or nonoccurrence of a stand replacement fire. If the character of the stand was altered resulting in regeneration loss, then the stand was considered to have the occurrence of a stand replacement fire. These stands are coded 4250 in the Oracle database. If the character of the stand was not altered without any regeneration loss, then the stand was considered to have the nonoccurrence of a stand replacement fire. These stands were coded 4981 in the Oracle database. The independent variables are site characteristics and management activities that occurred in the regeneration stand.

With logistic regression, the outcome or dependent variable is dichotomous with only two possible outcomes. In this study, the outcome is either the occurrence (1) or nonoccurrence (0) of a stand replacement fire. The distribution of the dependent variable is binomial with the conditional mean bounded between zero and one. The binomial distribution also characterizes the distribution of errors (Hosmer and Lemeshow 1989).

Multivariable logistic regression analyses was conducted following the recommendations of Hosmer and Lemeshow (1989).

For each category associated with an independent variable and continuous independent variables, the statistics reported in logistic regression include an odds ratio and 95% confidence interval for the odds ratio (Norusis 1997). The odds ratio identifies the category within a variable that is “most at risk” for a stand replacement fire and subsequent regeneration loss in comparison to a reference category. The reference category for each variable was the category that experienced the least amount of stand replacement fire. For this publication, the odds ratio will be discussed to identify the fuel treatment and site characteristics that may be used to prioritize management activities.

For continuous independent variables identified as significant from the regression analysis, a two-sample t-test was performed to best depict the independent variable relationship to the dichotomous dependent variable. Cases were separated into those stands receiving stand replacement fire and those that did not to form the two samples.

Objective two, model validation, was addressed by randomly sub-setting the 90% of the database to build the prediction model. Once the prediction model was constructed, the observations in the remaining 10% of the database were check for the difference in observed and predicted. The database was sub-setted in this fashion ten times such that all of the observations (N=135) were checked against a prediction model. A contingency table with the results of the observed and predicted findings was constructed and chi-square test was performed to check for model accuracy.

Following the cutoff values used by Hosmer and Lemeshow (1989), a stand replacement fire was considered to have occurred when the predicted probability value was greater than or equal to 0.5. When the predicted probability value was less then 0.5, the stand replacement fire was considered not to have occurred.

Objective three was accomplished by conducting ANOVA to compare difference in means for continuous variables across categories of the independent variables. If the ANOVA showed that there was a difference in means across the categories at the 0.05 alpha level, then a Scheffe test was conducted to identify the pairs of categories whose means were significantly different.

All tests were analyzed at the 0.05 alpha level of significance. All p-values greater than 0.05 were considered not significant while all p-values less than 0.05 were considered significant.

RESULTS

Objective 1

Multiple logistic regression analysis indicated that a four variable model containing the variables aspect, habitat type, fuel treatment, and log TPA were of the greatest significance ($p<0.04$) and explained the greatest amount of variation ($R^2=0.523$).

Several models were constructed in an attempt to best categorize the independent variables and enhance model performance. Aspect, with categories defined in the eight cardinal directions performed the best. Defining aspect by four categories in the northerly, east, southerly, and west categories reduced model performance. The database originally contained twenty-eight different habitats with some habitat types keyed to phase. Modeling was initially attempted with eight categories including those with phases. The “other” category included all those habitat types that had five or less observations. However, best model performance was obtained when two of the categories that were keyed to phase were combined with their perspective habitat types resulting in six categories. The fuel treatment variable, with three categories, did not improve model performance with any changes in category definition. Using a log transformation of TPA did improve model performance by reducing the influence of some TPA outliers.

Odds ratios, generated by logistic regression, identified the categories within a variable that are “most at risk” of a stand replacement fire and subsequent regeneration loss (Table 2).

Figure 2 shows the boxplot of TPA by the dichotomous dependent variable. Those stands that were considered not to have the stand replacement event occur (0) were placed in the no stand replacement fire group (NO SRF). Those that were considered to have the stand replacement fire occur (1) were placed in the stand replacement fire group (SRF). Figure 3 shows

Variable	Odds Ratio *	95% CI **
Aspect		
Reference East		
Southwest	22	2.6-177.5
South	9	1.2-69.1
North	8	0.6-96.7
West	7	1.1-43.0
Northwest	3	0.4-16.7
Northeast	1	0.1-4.5
Southeast	1	0.1-3.0
Habitat Type		
Reference Subalpine Fir/Sitka Alder		
Western Hemlock/Queencup Beadlily	30	4.2-214.1
Western Redcedar/Queencup Beadlily	17	1.1-257.0
Subalpine Fir/Queencup Beadlily	8	1.0-54.0
Other	6	1.0-32.1
Subalpine Fir/Menziesia	1	0.1-8.1
Fuel Treatment		
Reference Pile and Burn		
No Fuel Treatment	11	1.3-86.0
Burn	3	0.9-7.6

Table 2. Results of regression odds ratios and 95% confidence intervals for categorical variables found significant in model.

* Rounded to the nearest whole number

** Rounded to the nearest tenth

the 95% confidence interval about the mean TPA by the no stand replacement fire and stand replacement fire groups.

Results from the two-sample t-test indicated that there was a significant difference between the mean log TPA of the NO SRF and SRF group (t=3.385, df=82, p=0.001). Actual mean TPA for the NO SRF group was 735 TPA while the SRF group was 444TPA (difference of 291 TPA).

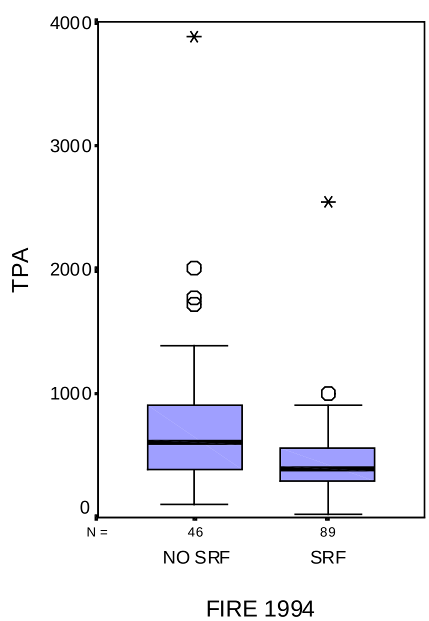

Figure 2. Boxplot of TPA by the dependent variable no stand replacement fire (NO SRF) and stand replacement fire (SRF).

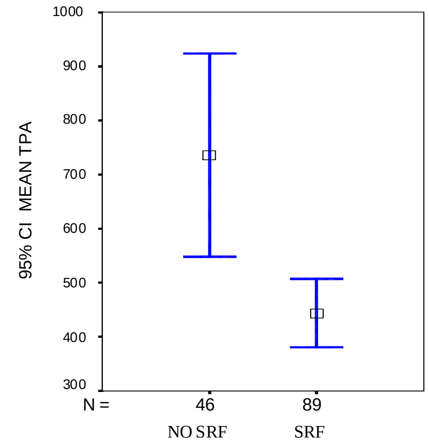

Figure 3. Mean TPA and 95% confidence interval for the mean for stands experiencing no stand replacement fire (NO SRF) and those experiencing stand replacement fire (SRF).

Objective 2

Results from the validation indicated that the four variable model correctly predicted overall 79% of the time (106 out of 135). The model correctly predicted the occurrence of a stand replacement fire when a stand replacement fire was observed 88% (78 out of 89) of the time. However, the model only correctly predicted the nonoccurrence of a stand replacement fire when the nonoccurrence was observed 61% (28 out of 46) of the time. Sixty-two percent of the model error (18 out of 29) was due to the model over predicting the occurrence of the stand replacement event when it was not observed (Table 3).

		PRED ICTED		Total
		0	1	
OBSE RVED	0	28 61%	18 39%	46 100%
	1	11 12%	78 88%	89 100%
	Total	39 29%	96 71%	135 100%

Table 3. Contingency table of observed and predicted stand replacement fire (1) and no stand replacement fire (0).

Results from the chi-square, used to test if there was a difference between what the model predicted and what was observed, indicated that there was no significant difference (χ^2 =32.4, df=2, p<0.001).

Objective 3

ANOVA results showed that there was a significant difference in mean log TPA across the classes of aspect categories (F=3.288, df=7, p=0.003). However, the Scheffe test determined that there was only one aspect pairing, northeast to south, in which the mean log TPA between the categories was significantly different (p=0.033). Actual mean TPA indicated a difference in mean of 388 TPA between the northeast and south aspects.

Figure 4 shows the distribution of TPA for the eight categories of aspect. Figure 5 shows the downward trend in mean TPA from the northerly to southerly aspects.

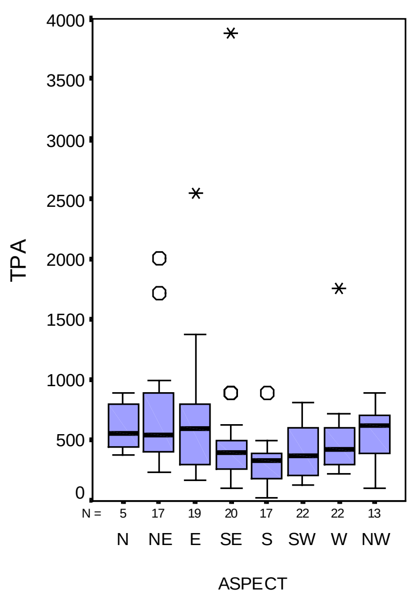

Figure 4. Boxplot of TPA by the eight aspect categories.

ANOVA results showed that there was a significant difference in mean log TPA across the classes of fuel treatment categories (F=3.601, df=2, p=0.03). The Scheffe test determined that there was one fuel treatment pairing, Burn Piles to Burn, in which the mean log TPA between the categories was significantly different (p=0.033). Actual mean TPA indicated a difference in mean of 221 TPA between the Burn Piles and Burn fuel treatment categories.

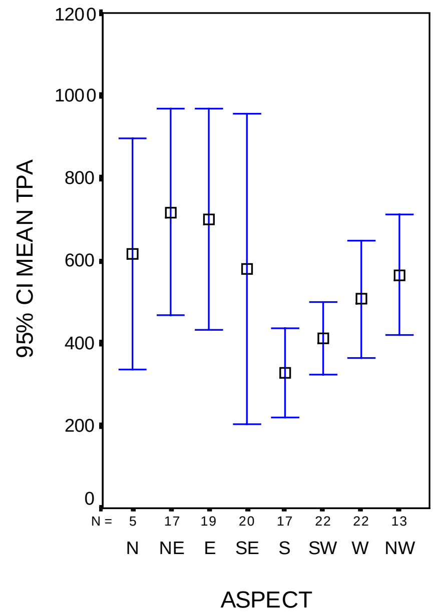

Figure 5. Mean TPA and 95% confidence interval for the eight aspect categories.

Figure 6 shows the distribution of TPA while Figure 7 shows the mean TPA for the three categories of fuel treatment.

ANOVA results showed that there was not a significant difference in mean log TPA across the classes of habitat type categories (F=0.746, df=5, p=0.59).

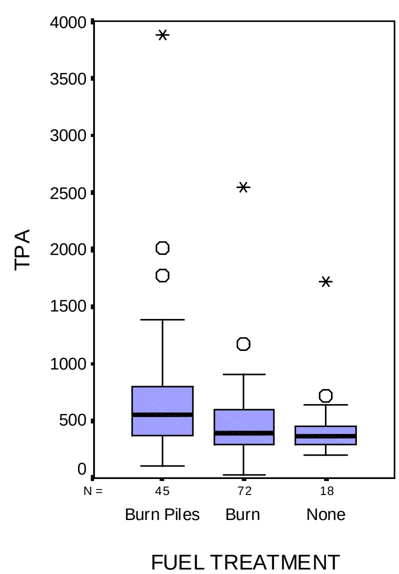

Figure 6. Boxplot of TPA by the three fuel treatment categories: Pile and Burn (Burn Piles), Burn (Understory, Broadcast, Jackpot), None (No Fuel Treatment).

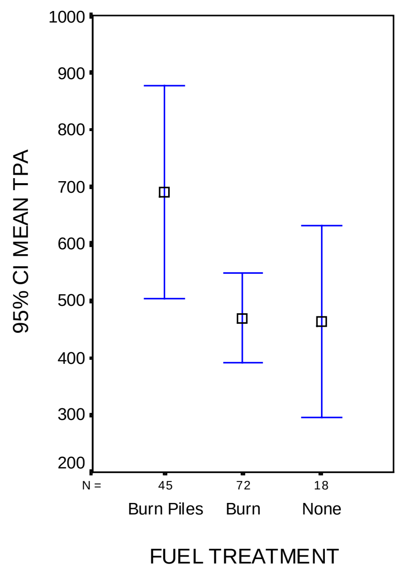

Figure 7. Mean TPA and 95% confidence interval for the three fuel treatment categories: Pile and Burn (Burn Piles), Burn (Broadcast, Understory, Jackpot), None (No Fuel Treatment).

DISCUSSION

Logistic regression resulted in the identification of four independent variables, aspect, habitat type, fuel treatment, and log TPA ($p<0.04$), that predicted stand replacement fire in regeneration stands ($R^2=0.523$) with the greatest degree of reliability. Model validation tests showed that there was no evidence that there was a difference ($\chi^2=32.4$, df=2, $p<0.001$) between the observed and predicted observations. The model, overall, predicting correctly 79 percent of the time. The model had the best performance when predicting the occurrence of stand replacement fire when stand replacement fire was observed (88 percent correct). However, the model did not predict the non-occurrence of stand replacement fire when stand replacement fire did not occur very well (61 percent correct). The majority of the error (62 percent) in the model was due to over predicting the occurrence of stand replacement fire.

Odds ratios calculated from logistic regression indicate that the southwest aspect was 22 times more at risk for a stand replacement fire compared to the east aspect, which had the least occurrence. South, north, west, northwest, northeast, and southeast were 9, 8, 7, 3, 1 and 1 times more at risk respectively.

Results obtained from ANOVA procedures indicated a significant difference ($F=3.288$, df=7,$p<0.003$) in mean log TPA across aspect categories. A graph of mean TPA by aspect category showed that there was a decreasing trend in mean TPA from the northerly to southerly aspects. The Scheffe test indicated that only one aspect pairing, northeast and south, had mean log TPA significantly different ($p< 0.04$).

These findings suggest that the southerly aspects are harsher and more difficult to regenerate. Shearer (1982 and 1989) and Ferguson (1994) obtained similar results when looking at regeneration success on different aspects.

Odds ratios for the habitat type variable indicated that the Western Hemlock/ Queencup Beadlily category was 30 times while the Western Redcedar/Queencup Beadlily was 17 times more at risk for a stand replacement fire.

The cause for these results might be due to the presence of bracken fern (*Pteridium aquilinum*) associated with cedar-hemlock stands. Bracken fern is prevalent in the early through mid-successional stages of cedar-hemlock stands (Zack and Morgan 1994) and will decrease with canopy closure (Mueggler 1965). Cedar-hemlock stands that have bracken litter are highly flammable and bracken fern has been considered to cause many reburns (Issac 1940, Haeussler and Coates 1990).

Bracken fern has many growth mechanisms that enhance its presence and survival following disturbance. A deeply rooted stem and rhizomatous growth allows the plant to survive cutting and severe burns (Cody and Crompton 1975, Lyon and Stickney 1976, and Stickney 1986). Regeneration occurs mainly from vegetative growth but it can colonize new areas, such as a logging site or burned soil, by spores (Haeussler and Coates 1990).

Bracken fern also possesses many characteristics that enable effective plant competition. Allopathic phytotoxins kill or decreases seed germination, reduce seedling vigor, or causes seedling mortality of other plants (Ferguson and Boyd 1988). Stickney (1986) found that bracken fern was able to retard tree and shrub development during the first decade after disturbance. Issac (1940) also observed that bracken fern out competed and eliminated tree seedlings, and persisted throughout the life of the stand when other herbaceous plants disappeared.

Methods of controlling bracken fern are limited. Some success has been achieved from repeated cutting (Haeussler and Coates 1990). Successful control of bracken fern has been achieved by using the herbicide Asulam or Glyphosate during frond emergence (Coates et al 1990 and Newton 1976).

ANOVA results indicated that there was not a significant difference ($p>0.05$) in mean log TPA across the habitat type classes.

Although the presence of bracken fern in cedar-hemlock stands may explain the fine fuel hazard that leads to the high risk of stand replacement fire in regeneration stands, I did not directly measure the presence or quantity of bracken fern. Thus, I can not draw direct conclusions about the effect of bracken fern on regeneration stand risk to stand replacement fire. Further research needs to be conducted on the effects of site preparation and the early serial stages of the various habitat types to clearly determine their relationship and the appropriate fuel treatment for a given habitat type.

Odds ratios for the variable fuel treatment indicated that the category no fuel treatment was 11 times, while the category burn was 3 times more at risk for a stand replacement fire compared to piled and burned stands. These results suggest that it did not matter how the fuels were treated, rather, what made the difference was that a fuel treatment did occur. Weatherspoon and Skinner (1995) also observed the importance of fuel treatment in harvested stands. In their study, all stands that had untreated fuels were burned completely and severely (Weatherspoon and Skinner 1995).

Results obtained from ANOVA procedures indicate a significant difference ($F=3.601$, $df=2$, $p<0.03$) in mean log TPA across Fuel Treatment categories. The Scheffe test indicated that stands that were piled and burned mean log TPA was higher and significantly different ($p<0.04$) from that of stands that were burned. While stands that were piled and burned had the highest mean log TPA, there was not a significant difference between the mean log TPA for piled and burned, and no fuel treatment stands. There was also no significant difference in mean log TPA between stands that were burned and no fuel treatment. The lack of significant difference between mean log TPA for piled and burned and no fuel treatment stands may be due to the high variability in no fuel treatment TPA observations. These results suggest that piling and burning may be a more effective site preparation for increasing TPA.

This study indicates that certain habitat types and stands on southerly aspects are more susceptible to a stand replacement fire while stands with high mean TPA are less susceptible to stand replacement fire. Adequate lowering of the fire hazard can be achieved with either burning or piling and burning the fuel created by harvesting as long as the fuel treatment is accomplished. Fire hazard may be increased in those cedar-hemlock stands that have bracken fern.

ACKNOWLEDGEMENTS

This study was funded by a Research Joint Venture Agreement (NO. INT-95080-RJVA) between the USDA FS, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula and the University of Montana as well as grant funds provided by the Blackfoot Forest Protective Association.

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